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Step 7. Evaluate other tiers. Continue a similar line of inquiry about the causal factor at each successive tier until satisfied that the causal factor is placed in the tier commensurate with the highest level of responsibility or authority for it. Again, as a causal factor is moved to higher tiers, note the letter designation in the tier from which it is moved. For example, if responsibility for causal factor "A" is found to reside with upper management, the letter "A" should appear in Tiers 1 through 4, with the actual adhesive note placed in Tier 5.

Step 8. Repeat for each causal factor. Repeat steps 1 through 7 for each causal factor previously placed in Tier 1 of the diagram.

Step 9. Identify linkages. After arranging all the causal factors on the tier diagram, examine the causal factors to determine whether there is linkage between two or more of them. For example, are two or three causal factors similar enough to indicate poor conduct of operations? Or perhaps several causal factors are related to a lack of worker training. If linkages exist, group the adhesive notes at the highest level where a linkage occurs (see Figure 7-9). For example, if causal factors "B" and "F" in Tier 3 are related to causal factor "H" in Tier 4, remove "B" and "F" (noting their location), and affix them to "H" in Tier 4. Next, if one of the causal factors statements accurately describes the commonality among the grouped causal factors, let that causal factor represent the grouping. If not, write a causal factor statement that captures the common theme of all the causal factors in that particular grouping. This statement becomes a potential root cause.

The board members should continue to examine all of the causal factors until they are satisfied that all applicable linkages have been made.

Step 10. Identify root causes. Evaluate each of the causal factor statements that now appear on the chart. Compare each statement to the definition of a root cause to determine whether it appears to be a root cause of the accident. This step will generally involve a great deal of discussion among board members.

TIP

If a causal factor does not meet the criteria for a root cause, do nothing, it remains a contributing cause of the accident.

If a causal factor (singly or representing a group) meets the criteria for a root cause, denote it as such either using the letters "RC" (root cause) or by some other means. You may find that you need to create a root cause statement based on one or more causal factors. If so, write a summary causal factor statement and place it on the appropriate tier. The board may choose to add a third column, "Root Causes," to the tier diagram (Table 7-6). The advantage of adding this column is that moving the root cause statements makes them stand out, along with the associated level of management responsibility.

The root cause analysis may reveal causal factors that are not on the events and causal factors chart. These should be added to both the events and causal factors chart and the tier diagram to assure that they are consistent and reflect all of the causal factors as a basis for root cause analysis.

Step 11. Simplify root cause statements. There may be more than one root cause of a particular accident, but probably not more than three. If there are more than that at the end of the tier diagram analysis, the board should re-examine the list of root causes to determine which ones can be further combined to reflect more fundamental deficiencies.

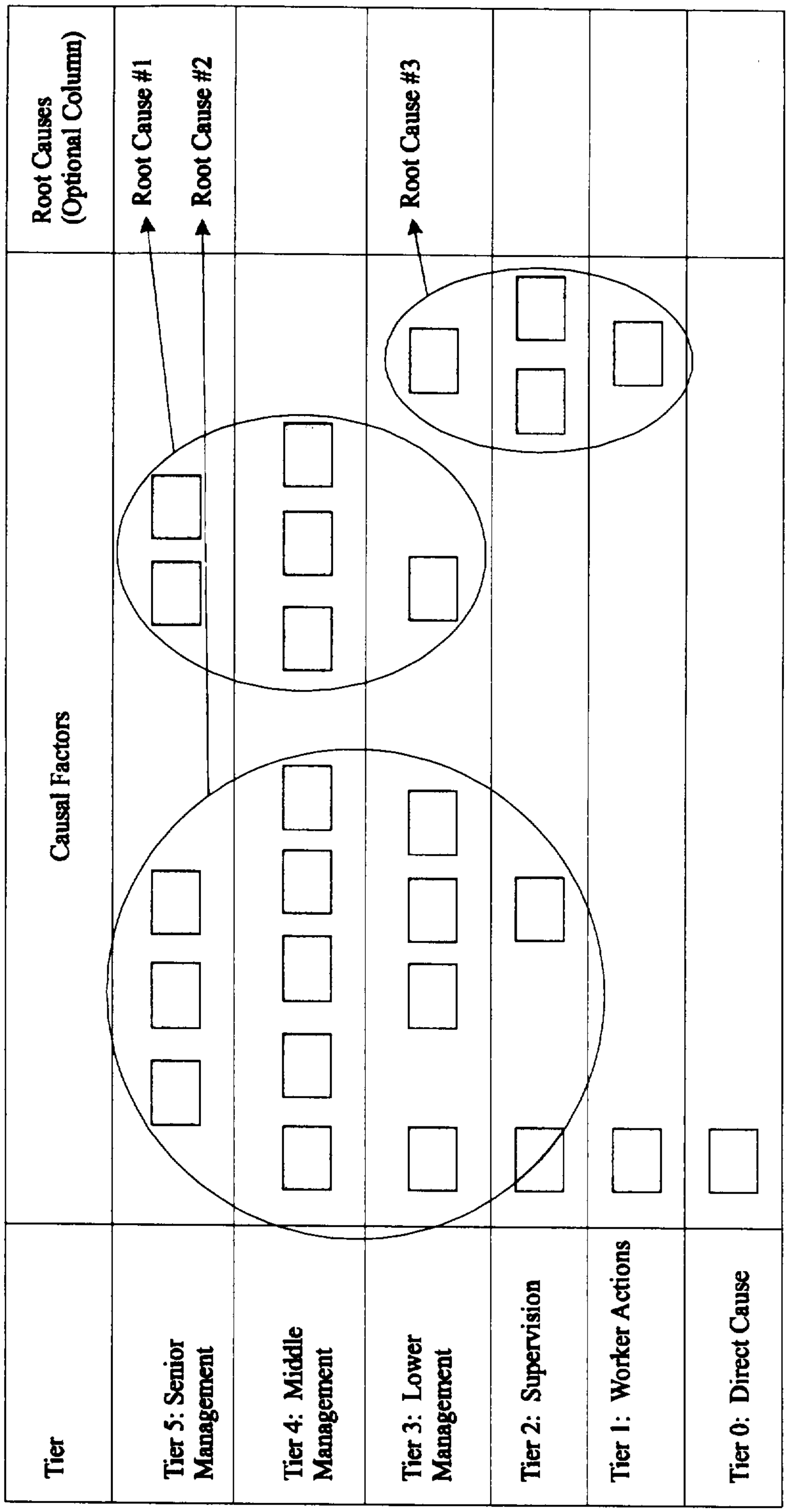


Figure 7-9. Identifying the linkages on the tier diagram.

When the board is satisfied that the root causes have been accurately identified and the number of root causes is not excessive, the root cause analysis is complete. The board should capture the essence of the root cause analysis for the accident investigation report, noting the direct, contributing, and root causes of the accident in order to develop judgments of need.

Guidelines and Reminders:

- Root causes may be found in any of Tiers 1 through 5. However, they are generally found in higher tiers because that is where managers are most responsible for directing and overseeing activities.

- The root cause of an accident can be found at the worker level of the tier diagram if, and only if, the following conditions are found to exist:

  - Management systems were in place and functioning, and provided management with feedback on system implementation and performance

  - Management took appropriate actions based on the feedback

  - Management, including supervision, could not reasonably have been expected to take additional actions based on their responsibilities and authorities.

- Root causes can be found at more than one level of an organization. For example, one root cause may be attributable to Tier 3, while two other root causes are attributable to Tier 5.

- Root causes are generally attributable to an action or lack of action by a particular group or individual in the line organization.

- Each "corporate" organization is considered separately for its responsibility in the accident. For example, in DOE, a management and operating (M&O) contractor would be considered as one organization, and DOE would be considered as a second organization. Consequently, the results of one tier diagram may be the input of another. For example, if the upper management of an M&O contractor was responsible for a particular root cause, DOE may share responsibility for that particular root cause—there may be a deficiency in the directives given from DOE, insufficient oversight, or some other DOE responsibility that was inadequately fulfilled.

Compliance/Noncompliance. The compliance/noncompliance technique is useful when investigators suspect non-compliance to be a causal factor. This technique compares evidence collected against three categories of noncompliance to determine the root cause of a noncompliance issue. As illustrated in Table 7-8, these are: "Don't Know," "Can't Comply," and "Won't Comply." Examining only these three areas limits the application of this technique; however, in some circumstances, an accident investigation board may find the technique useful.

The basic steps for applying the compliance/noncompliance technique are:

- Have a complete understanding of the facts relevant to the event

- Broadly categorize the noncompliance event

- Determine why the noncompliance occurred (i.e., the subcategory or underlying cause).

Table 7-8. Compliance/Noncompliance Root Cause Model Categories.

Don't Know		Can't Comply		Won't Comply	
Never knew	This is often an indication of poor training or failure in a work system to disseminate guidance to the working level.	Scarce resources	Lack of funding is a common rebuttal to questions regarding noncompliance. However, resource allocation requires decision-making and priority-setting at some level of management. Boards should consider this line of inquiry when examining root causes pertaining to noncompliance issues.	No reward	An investigator may have to determine whether there is a benefit in complying with requirements or doing a job correctly. Perhaps there is no incentive to comply.
Forgot	This is usually a local, personal error. It does not reflect a systemic deficiency, but may indicate a need to increase frequency of training or to institute refresher training.	Don't know how	This issue focuses on lack of knowledge (i.e., the knowhow to get a job done).	No penalty	This issue focuses on whether sanctions can force compliance, if enforced.
Tasks implied	This is often a result of lack of experience or lack of detail in guidance.	Impossibility	This issue requires investigators to determine whether a task can be executed. Given adequate resources, knowledge, and willingness, is a worker or group able to meet a certain requirement?	Disagree	In some cases, individuals refuse to perform to a standard or comply with a requirement that they disagree with or think is impractical. Investigators will have to consider this in their collection of evidence and determination of root causes.

For example, investigators may use this technique to determine whether an injured worker was aware of particular safety requirements, and if not, why he or she was not (e.g., the worker didn't know the requirements, forgot, or lacked experience). If the worker was aware but was not able to comply, a second line of questioning can be pursued. Perhaps the worker could not comply because the facility did not supply personal protective equipment. Perhaps the worker would not comply in that he or she refused to wear the safety equipment. Lines of inquiry are pursued until investigators are assured that a root cause is identified.

Lines of questioning pertaining to the three compliance/noncompliance categories follow. However, it should be noted that these are merely guides; an accident investigation board should tailor the lines of inquiry to meet the specific needs and circumstances of the accident under investigation.

- **Don't Know:** Questions focus on whether an individual was aware of or had reason to be aware of certain procedures, policies, or requirements that were not complied with.

- **Can't Comply:** This category focuses on what the necessary resources are, where they come from, what it takes to get them, and whether personnel know what to do with the resources when they have them.

- **Won't Comply**: This line of inquiry focuses on conscious decisions to not follow specific guidance or perform to a certain standard.

By reviewing collected evidence, such as procedures, witness statements, and interview transcripts, against these three categories, investigators can pursue suspected compliance/noncompliance issues as root causal factors.

Although the compliance/noncompliance technique is limited in applicability, by systematically following these or similar lines of inquiry, investigators may identify root causes and judgments of need.

Automated Techniques. Several root cause analysis software packages are available for use in accident investigations. Generally, these methods prompt the investigator to systematically review investigation evidence and record data in the software package. These software packages use the entered data to construct a tree model of events and causes surrounding the accident. In comparison to the manual methods of root cause analysis and tree or other graphics construction, the computerized techniques are quite time-efficient. However, as with any software tool, the output is only as good as the input; therefore, a thorough understanding of the accident is required in order to use the software effectively.

Many of the software packages currently available can be initiated from both PC-based and Macintosh platforms. The Windows™ based software packages contain pulldown menus and employ the same use of icons and symbols found in many other computer programs. In a step-by-step process, the investigator is prompted to collect and enter data in the templates provided by the software. For example, an investigator may be prompted to select whether a problem (accident or component of an accident) to be solved is an event or condition that has existed over time. In selecting the "condition" option, he or she would be prompted through a series of questions designed to prevent a mishap occurrence; the "event" option would initiate a process of investigating an accident that has already occurred.

TIP

Analytical software packages can help the board:

- *Remain focused during the investigation*
- *Identify interrelationships among data*
- *Eliminate irrelevant data*
- *Identify causal factors (most significantly, root causes).*

The graphics design features of many of these software packages can also be quite useful to the accident investigation board. With little input, these software packages allow the user to construct preliminary trees or charts; when reviewed by investigators, these charts can illustrate gaps in information and guide them in collecting additional evidence.

It is worth underscoring the importance of solid facts collection. While useful, an analytic software package cannot replace the investigative efforts of the board. The quality of the results obtained from a software package is highly dependent on the skill, knowledge, and input of the user.

7.3 Using Advanced Analytic Methods

The four core techniques can be effectively applied to many investigations, but the analysis of more complex accidents may have to be supplemented with more sophisticated techniques. These techniques require in-depth knowledge and specialized expertise beyond the scope of this workbook. However, several are discussed briefly here to ensure awareness of their applicability to the accident investigation process. The chairperson, board members, and any subject matter experts should determine which methods to employ, based on their familiarity with various methods and the severity and complexity of the accident.

7.3.1 Analytic Trees

Analytic tree analyses are well defined, useful methods that graphically depict, from beginning to end, the events and conditions preceding and immediately following an accident. An analytic tree is a means of organizing information that helps the investigator conduct a deductive analysis of any system (human, equipment, or environmental) to determine critical paths of success and failure. Results from this analysis identify the details and interrelationships that must be considered to prevent the oversights, errors, and omissions that lead to failures. In accident investigations, this type of analysis can consist of both failure paths and success paths, and can lead to neutral, negative, or positive conclusions regarding accident severity.

TIP

An analytic tree enables the user to:

- *Systematically identify the possible paths from events to outcome*
- *Display a graphical record of the analytical process*
- *Identify management system weaknesses and strengths.*

The analytic tree process begins by clearly defining the accident; "branches" of the tree are constructed using logic symbology. Following is a summary overview of the approach to constructing an analytic tree, which is illustrated in Figure 7-10. It should not be inferred that this is the only way to construct or use analytic trees, since a variety of analytic tree methods is available.

As the events at the bottom branches of the tree become more specific, the causal factors of the accident are developed. When the event at the bottom contains no other events that allowed it to occur, a decision

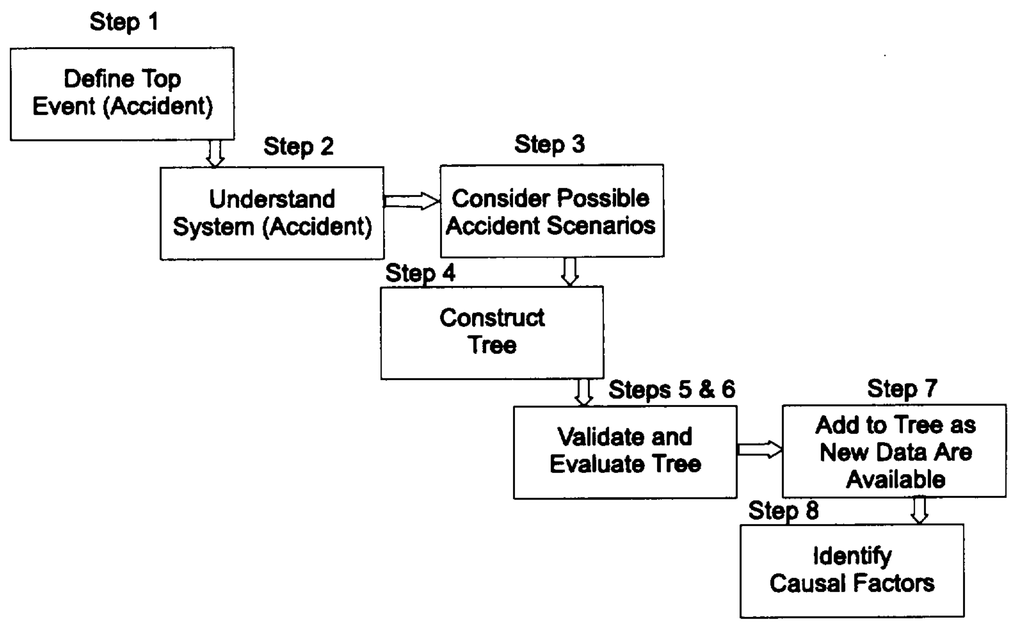


Figure 7-10. The analytic tree process begins with the accident as the top event.

must be made regarding whether the event is a causal factor or is not relevant to the outcome of the accident (top event). When processed through the logic gate, each bottom tier should be necessary and sufficient to lead directly to the failure or success of the event on the next higher tier.

The steps required to prepare an analytic tree are described below.

Step 1. Define the top event as the accident. As in events and causal factors analysis, the event should be defined as a single, discrete event, such as "worker strikes 13.2 kV primary feeder cable."

Step 2. Acquire a working knowledge of the accident effects, the work situation, and the upstream processes that preceded them. A comprehensive understanding of the management system is also needed to develop the tree.

Step 3. Based on the facts, postulate the possible scenarios by which the accident occurred. All accidents are complex events that become interrelated to produce the unwanted event (accident). This step should force the investigator to analyze the facts of the accident and try to visualize all possible scenarios. As the investigation continues and as new evidence is introduced, a different scenario could develop. Before the tree is constructed, it is important to visualize it using different possible scenarios consistent with the facts.

Step 4. Construct the analytic tree, starting with the top event and using the proper logic gates and symbols. The tiers beneath the top event should explain the reason for failure or success of that event. The proper use of symbols and transfers is crucial to understanding this graphic model.

Step 5. It is important for each board member to validate the analytical tree for completeness, logic, and accuracy. As new facts and evidence are discovered, the tree must be updated to reflect these changes. The validation process should begin as soon as the tree is constructed. The purpose of this validation review is to confirm that:

- The tree meets its intended objectives
- The management systems are fully and clearly described
- Inputs to logic gates are necessary and sufficient to logically produce the stated output events.

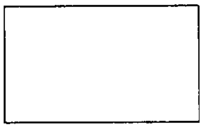
Step 6. Each relationship between events should be evaluated to determine the causal factors of the accident (top event). As these tiers flow down to the end events, the specific events of the analytic tree will be developed and will help describe why the top event occurred, by organizing the accident's evidence in a way that helps the board identify the accident's causal factors. Though the chart is highly structured, identifying root causes is not a mechanical process. Considerable reasoning and judgment are required from the board to determine root and contributing causes.

Step 7. Add to the analytic tree as new evidence is acquired and new possible scenarios are developed. The tree must be a working analytical tool that will have several iterations before the final tree is developed. If new possible scenarios are introduced, do not reject the scenario if it does not fit the tree. It might be necessary to construct a new tree for a new scenario. It is important that all possible scenarios be considered; they should be rejected only because they do not fit the facts, not because they are improbable.

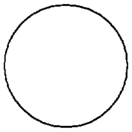
Step 8. Through the iterative process of fact-finding and analysis identify the causal factors.

The basic conventions for constructing an analytic tree are to:

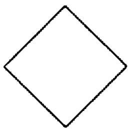
- Use common and accepted graphic symbols for events, logic gates, and transfers. (Figure 7-11 displays the symbols used in analytic trees.)
- The analytic tree should be constructed as simply as the accident allows. The tree should flow logically from the top event to the more specific events. If an event occurs that has no relevance to the accident, a diamond symbol should note that there is no further development of this event.
- Keep the tree logical. The tree should be validated at each level to ensure that each contributing event logically proceeds to the top event. The lower-tier input events should be only those that are necessary and sufficient to produce the next tier event. It is important for events to logically flow to other events that are supported by the facts.
- Use the proper logic gate that describes the relationship between the events. The proper selection and use of the logic gates will identify the interaction between lower-tier events and the top event.
- The event descriptions should be simple, clear, and concise. The descriptions should be sufficiently detailed and logical that they can be understood without referring to another section.
- The final analytic tree should be limited in the number of tiers placed on a single page. For legibility and readability, it is best that only four or five tiers be placed on a single page.
- Use a common numbering system for the events. Each event is identified by the decimal numbering system. The number of digits in the decimal event numbering system should correspond to the tier on which the event is located. (For example, the fourth tier will contain four digits.) This system for numbering will uniquely describe an event and systematically trace its development through subbranches and branches to the first-tier event. Each



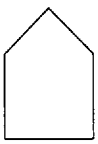
Rectangle (General Basic Event) - The primary building block for analytic trees. Event resulting from the combination of more basic events acting through logic gates.

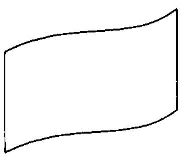


Circle (Basic Event) - The symbol used for the bottom tier of the tree to indicate development is complete. Event is not dependent on other events.

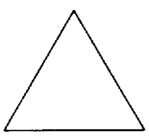


Diamond (Undeveloped Event) - An event that is not further developed either because it is of insufficient consequence or because information is unavailable.

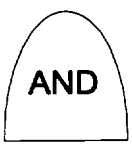




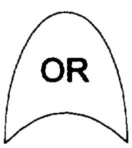
House or Scroll (External Event) - An event that is normally expected to occur. The house is used for analytic trees, and the scroll is used for MORT.



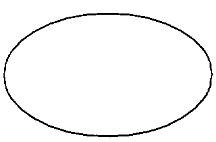
Triangle - Transfer symbol.



AND Gate - All inputs are required to produce output.



OR Gate - Only one or any combination of inputs is required to generate output event.



Ellipse (Conditioning Event) - Applies conditions or constraints to basic logic gates or output events.

Figure 7-11. Analytic trees are constructed using symbols.

successively higher-level event can be identified by dropping the last digit from the number. For example:

	Top Event
1	First Tier
1.1	Second Tier
1.1.1	Third Tier
1.1.1.1	Fourth Tier
1.1.1.1.1	Fifth Tier

- A modified decimal system for numbering events can be adapted for transfer symbols, beginning with the letter designation for the transfer. If the transfer letter is A, then the corresponding numbers could be A.1.3.2. The numbering system is the same as the decimal system, with an alphabetic symbol as the first digit corresponding to the transfer. The fourth subtier that is transferred would be labeled as shown below:

D	Transfer
D.2	First Subtier
D.2.2	Second Subtier
D.2.2.1	Third Subtier
D.2.2.1.2	Fourth Subtier

- Use transfers to avoid duplication of identical branches or segments of the tree and to reduce single-page tree complexity. Whenever two or more gate output events have identical details in the substructures contributing to their occurrence, that substructure should be constructed under only one of the output events; it should then be transferred to the others through the use of transfer symbols. The event must be identical to be transferrable. Transfers should also be used below the bottom-tier events on a page to indicate continuance of subbranches of those events on other pages. Whenever there is insufficient space on a page to develop a branch below an event at any level, a transfer immediately below that event indicates that the branch is developed on another page.

- Do not number or letter logic gates; use numeric and alphanumeric decimal identification designations only for events.

- Follow the left-to-right convention of indicating time sequencing or order of performance for related events on a single tier. It should also be apparent that a higher-tier event has greater significance (more impact on the top event) and occurs later than the more detailed contributory events located on lower tiers within its branch.

Figure 7-12 shows an example format for the layout of an analytic tree. Although each accident will dictate its own shape, this example displays all elements in an analytic tree. Figure 7-13 is an example of a completed analytic tree for a grinding wheel accident. The lowest tier shows that the tool rest was not set correctly, the operator did not wear goggles, and the machine guard was removed for convenience. This example displays how the lower-tier elements contribute (flow) to the top event.

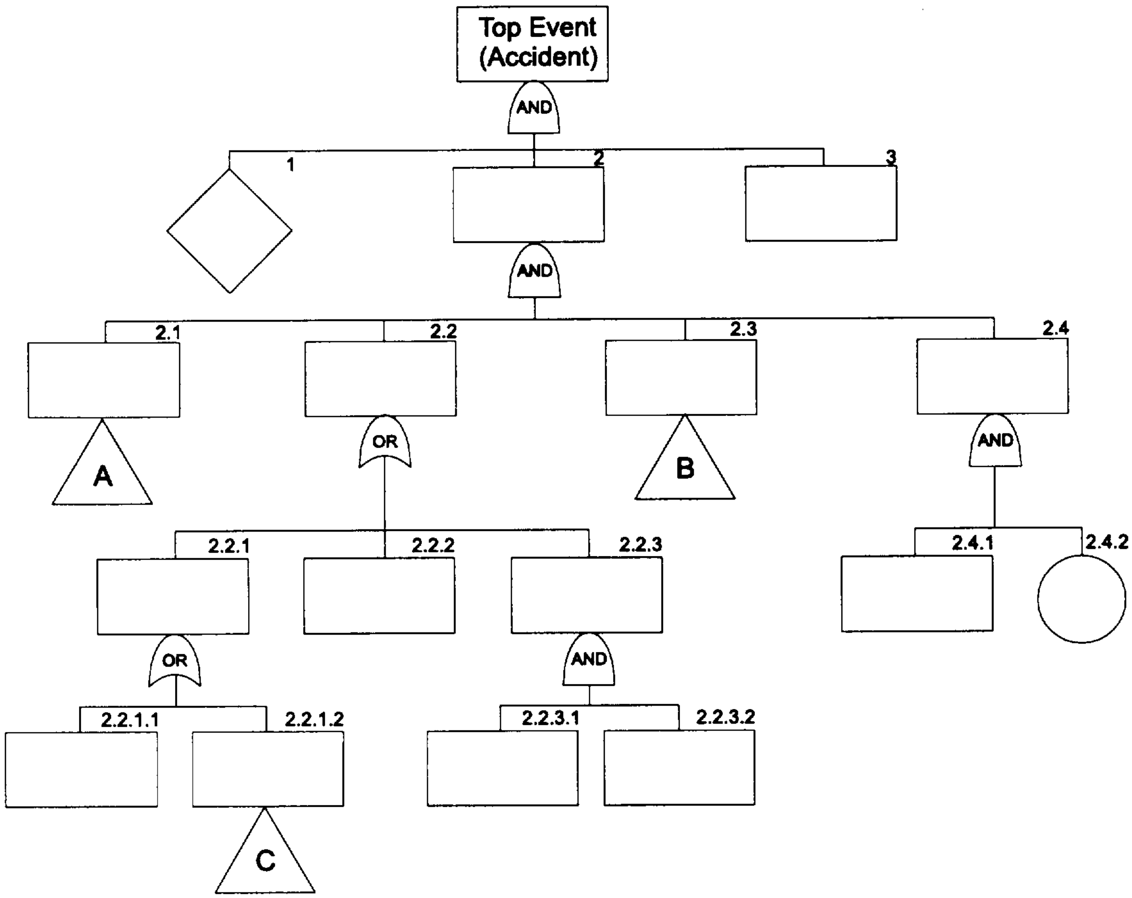


Figure 7-12. The layout of an analytic tree shows logical relationships.

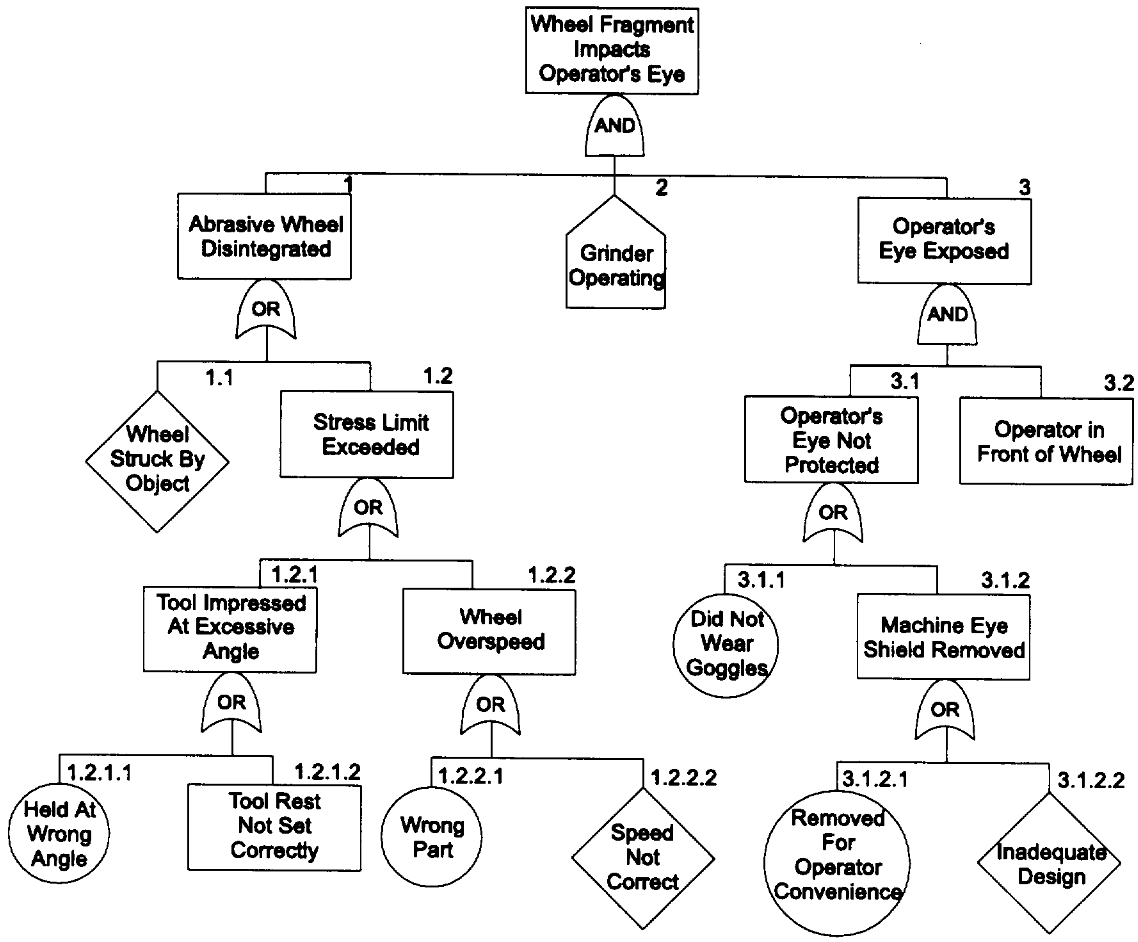


Figure 7-13. A completed analytic tree shows the flow of lower-tier elements to the top event.

7.3.2 Management Oversight and Risk Tree Analysis (MORT)

MORT—a comprehensive analytical tree technique—was originally developed for DOE to help conduct nuclear criticality and hardware analysis. It was later adapted for use in accident investigations and risk assessments. Basically, MORT is a graphical checklist, but unlike the events and causal factors chart, which must be filled in by investigators, the MORT chart contains generic questions that investigators attempt to answer using available factual data. This enables the investigator to focus on potential key causal factors. The MORT chart's size can make it difficult to learn and use effectively. For complex accidents involving multiple systems, such as nuclear systems failures, MORT can be a valuable tool but may be inappropriate for relatively simple accidents. MORT requires extensive training to effectively perform an in-depth causal analysis of complex accidents. If needed, the MORT analysis is usually performed by board members with substantial previous experience in using the MORT techniques.

The ***benefits*** *of MORT are that it:*

- *Uses the analytic tree method to systematically dissect an accident*
- *Serves as a detailed road map by requiring investigators to examine all possible causal factors (e.g., assumed risk, management controls or lack of controls, and operator error)*
- *Looks beyond immediate causes of an accident and instead stresses close scrutiny of management systems that allowed the accident to occur*
- *Permits the simultaneous evaluation of multiple accident causes through the analytic tree.*

In evaluating accidents, MORT provides a systematic method (analytic tree) for planning, organizing, and conducting a comprehensive accident investigation. Through MORT analysis, investigators identify deficiencies in specific control factors and in management system factors. These factors are evaluated and analyzed to identify the causal factors of the accident.

Detailed knowledge and understanding of management and operating systems is a prerequisite to a comprehensive MORT analysis. Therefore, it is most effective if investigators have collected substantial evidence before initiating the MORT process. The management system data required include procedures, policies, implementation plans, risk assessment program, and personnel. Information about the facility, operating systems, and equipment is also needed. This information can be obtained through reviews of physical evidence, interview transcripts, management systems, and policies and procedures.

The symbols used on the MORT chart are similar to those used for other analytical trees. The symbols that differ for the MORT chart are the scroll ("normally expected" event) and the oval ("satisfactory" event). The "normally expected" event distinguishes events that are typically a part of any system, such as change and normal variability. The "satisfactory" event describes events that may be accident causal factors but are a necessary part of the operation, such as "functional" (part of the system) and people or objects in the energy channel. In addition to using the traditional transfer symbol (triangle), the MORT chart includes capital letters as drafting breaks and small ovals as risk transfers.

The first step of the process is to obtain the MORT charts and select the MORT chart for the safety program area of interest evaluating each event. Next, the investigators work their way down through the tree, level by level, proceeding from known to unknown. Events should be coded in a specific color relative to the significance of the event (accident). The color-coding system used in MORT analysis is shown in Table 7-9. An event that is deficient, or less than adequate (LTA) in MORT terminology, is marked red. The symbol is circled if suspect or coded in red if confirmed. An event that is satisfactory is marked green in the same manner. Unknowns are marked in blue, being circled initially and colored in if sufficient data do not become available, and an assumption must be made to continue or conclude the analysis.

It is not useful to start on the first day by marking everything as needing more information (color-coded blue). Instead, start marking the first MORT chart with red and black for events where there is sufficient evidence. Ideally, all blue blocks eventually are replaced by one of the other colors; however, this may not always be possible.

Table 7-9. MORT Color Coding System.

Color Code	Significance
Red	The event is less than adequate. Corrective actions are needed. All events colored red must be documented and supported with facts
Green	The event is satisfactory and adequate. Credible evidence must support this event to ensure that no corrective actions need to be identified for this event.
Blue	The event has insufficient evidence or information to evaluate. Additional facts or evidence must be collected to analyze this event.
Black	The event is not applicable or relevant to the accident. The event does not need any further investigation.

When the appropriate segments of the tree have been completed, the path of cause and effect (from lack of control by management, to basic causes, contributory causes, and root causes) can easily be traced back through the tree. This becomes a matter of following the red events through the various logic gates. The tree highlights quite clearly where controls and corrective actions are needed and can be effective in preventing recurrence of the accident.

Figures 7-14 through 7-16 show three MORT charts. Figure 7-14 displays the injury, damage, other costs, performance lost, or degraded event. Figure 7-15 describes the incident, barriers, and persons or objects. Figure 7-16 is an evaluation of the management system factors.

7.3.3 Project Evaluation Tree (PET) Analysis

PET is an efficient means of performing an in-depth analysis of an operation, project, or system. This analytical tree method is best suited for performing hazard and accident analyses, but it can also be used to identify preventive measures. PET was developed to capture the philosophy and methodology of MORT, but eliminate the complexity of the more than 1500 logic gates in MORT.

Using PET in an accident investigation requires detailed information regarding the various components of the system, operation, or accident situation, such as procedures, personnel, facilities, and equipment. Using logic symbology, an analyst traces each component of a system through the tree's branches to evaluate each element as a potential causal factor.

TIP

The key benefits of the PET analysis are that it:

- *Provides a simplified approach that applies the tenets of MORT*
- *Categorizes information into three main branches—procedures, personnel, and plant or hardware—enabling investigators to examine the factors that impact an accident relatively simply and quickly.*

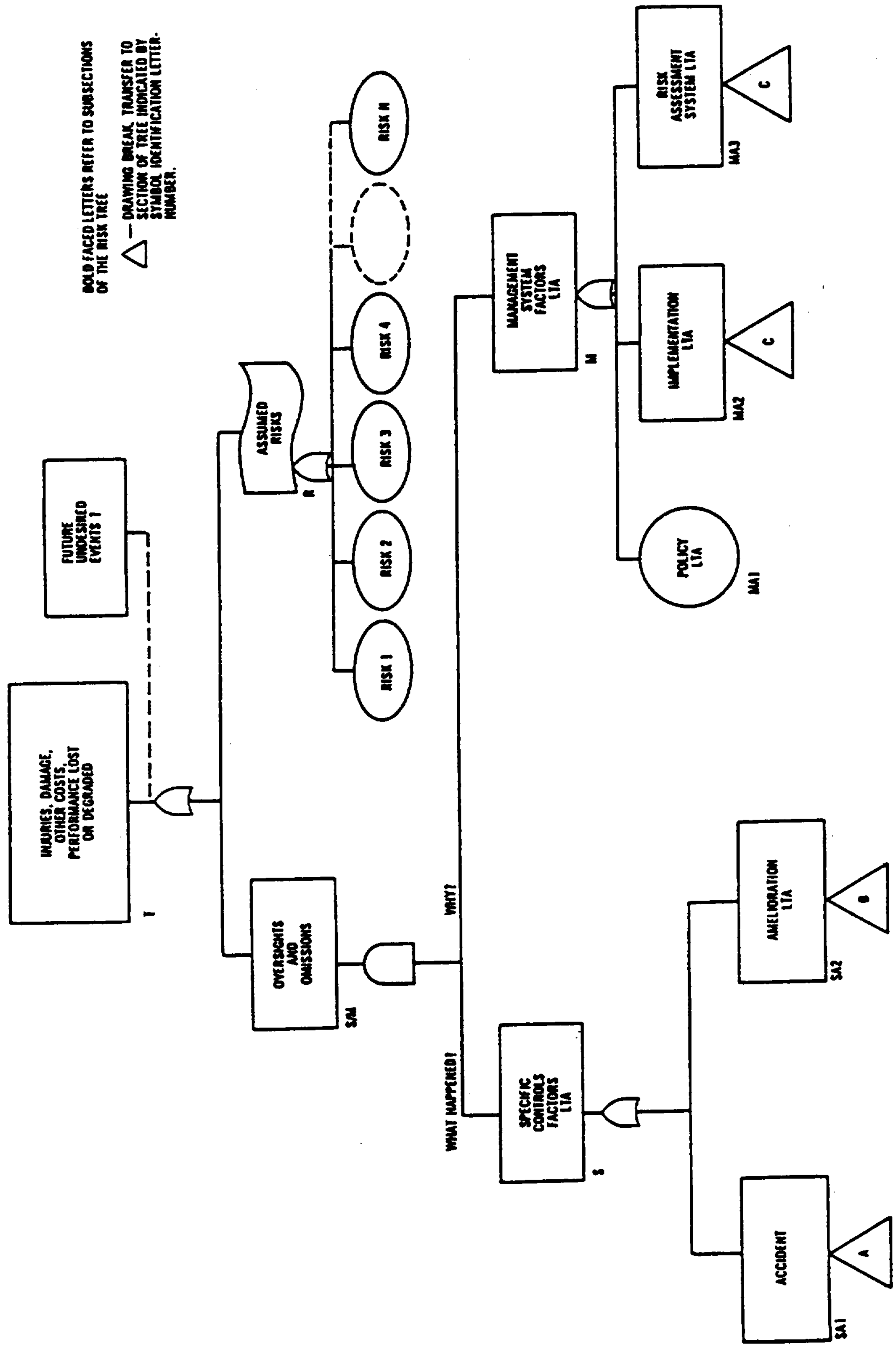


Figure 7-14. The initial MORT chart uses logic symbols.

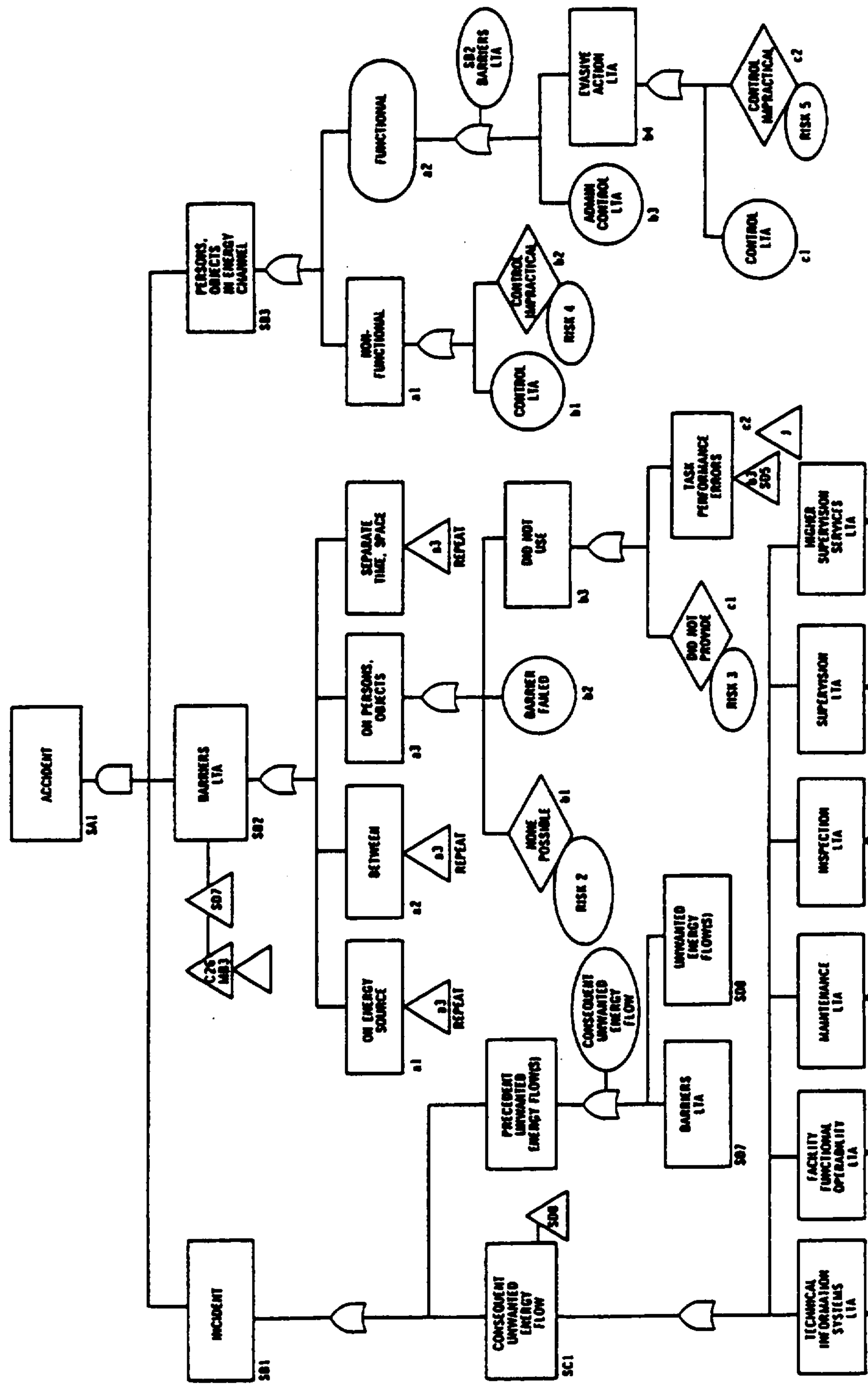


Figure 7-15. The accident description can be shown on a MORT chart.

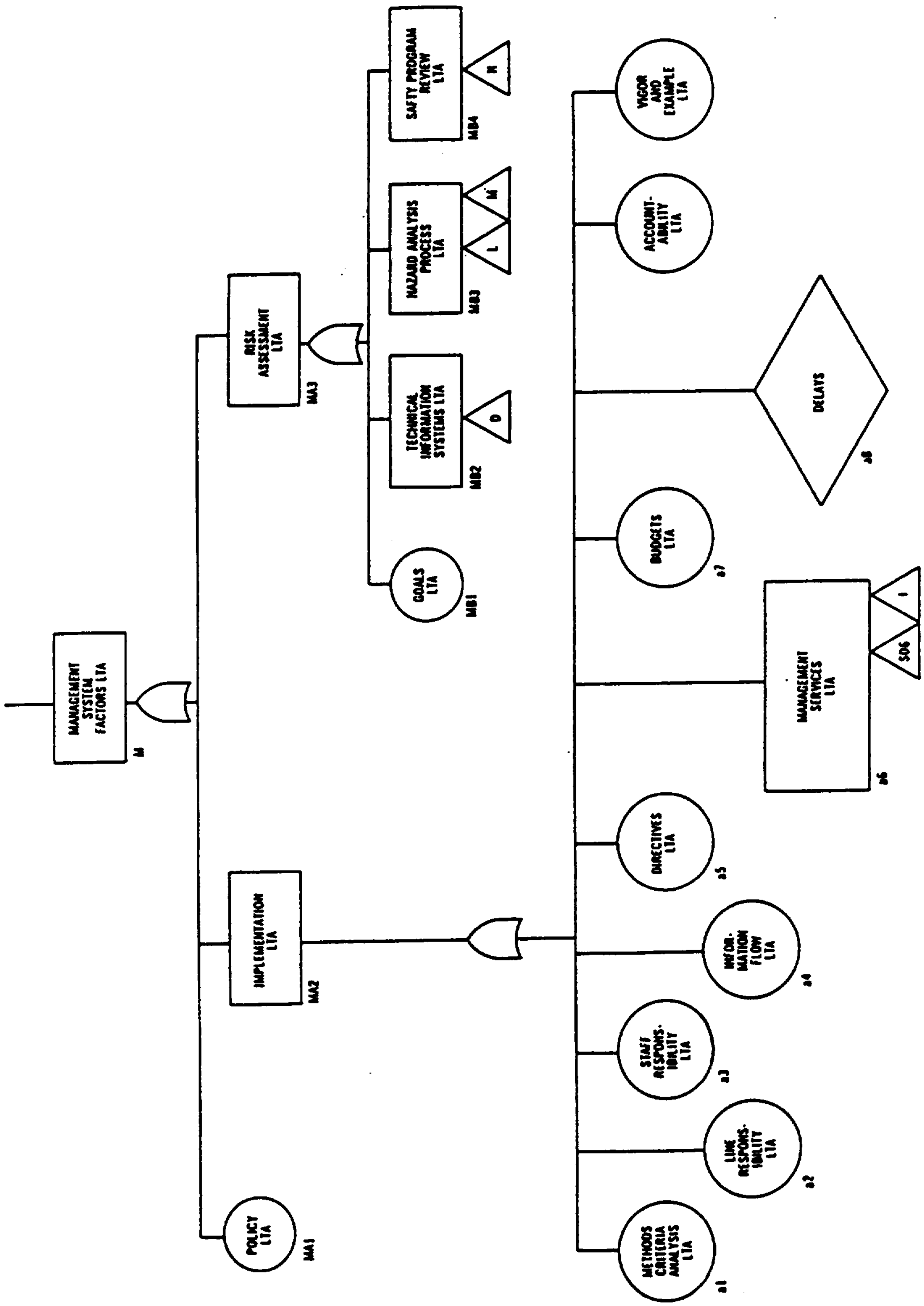


Figure 7-16. Management system factors can be shown on a MORT chart.

PET is structured for evaluation and analysis of procedures, personnel, and facilities/hardware. (An example of a PET chart used to analyze procedures is shown in Figure 7-17.) PET analysis requires detailed information on these three dimensions. Evaluation of procedures requires procedural instructions, reviews and safety evaluations, work plans, work package instructions, and other data. Personnel evaluation requires job descriptions, organizational charts, training records, course curricula, course materials, interviews, and other data. If the accident was facility- or hardware-related, then drawings, procurement documents, specifications, test plans, system safety plans, hazard analyses, and budget data are required to conduct a comprehensive PET analysis. The scope and depth of the accident investigation dictate the input requirements.

The first step is to organize the data into procedures, personnel, and facilities/hardware. These data are then systematically evaluated using the appropriate PET chart. The next step is to color-code the events. Red is used for events that are less than adequate (LTA), green for events that are satisfactory (adequate), black for events that are not relevant to the accident, and blue for areas that need additional investigation or analysis to reach a decision. (This color-coding system is the same system used for MORT.)

After the chart is completed and the events are color-coded, PET worksheets should be used to evaluate each red item. A PET analysis worksheet is provided at the end of this section. This worksheet is similar to the barrier analysis and change analysis worksheets. It provides the basis for the narrative summary of the analysis.

7.4 Other Analytic Techniques

Other analytic techniques may be used for specific investigations, depending on the nature and complexity of the accident. Ultimately, the analytic techniques used in any investigation should be determined by the board chairperson with input from the board members and advisors/consultants. To conduct an effective and timely investigation, the choice normally should be limited to the techniques discussed above. However, if warranted by the circumstances of the accident investigation, experts in various analytic methods may be called upon to use other analytic techniques. It is also important for investigators to understand that many of these analytical processes may have been completed prior to the accident and may be included in authorization basis documentation (e.g., safety analysis reports). This information is useful to the board in developing and understanding its own analysis of the accident. Following are brief descriptions of additional analytic techniques that might be used.

The list of techniques provided in this workbook is not exhaustive. Other analytic techniques that may yield important results for a particular investigation may be necessary and used at the board's discretion.

7.4.1 Time Loss Analysis

Time loss analysis evaluates emergency response performance. The basic assumption of this technique is that every accident sequence has a natural progression that would occur without outside intervention by emergency response personnel (e.g., a fire would eventually burn out without the aid of firefighters).

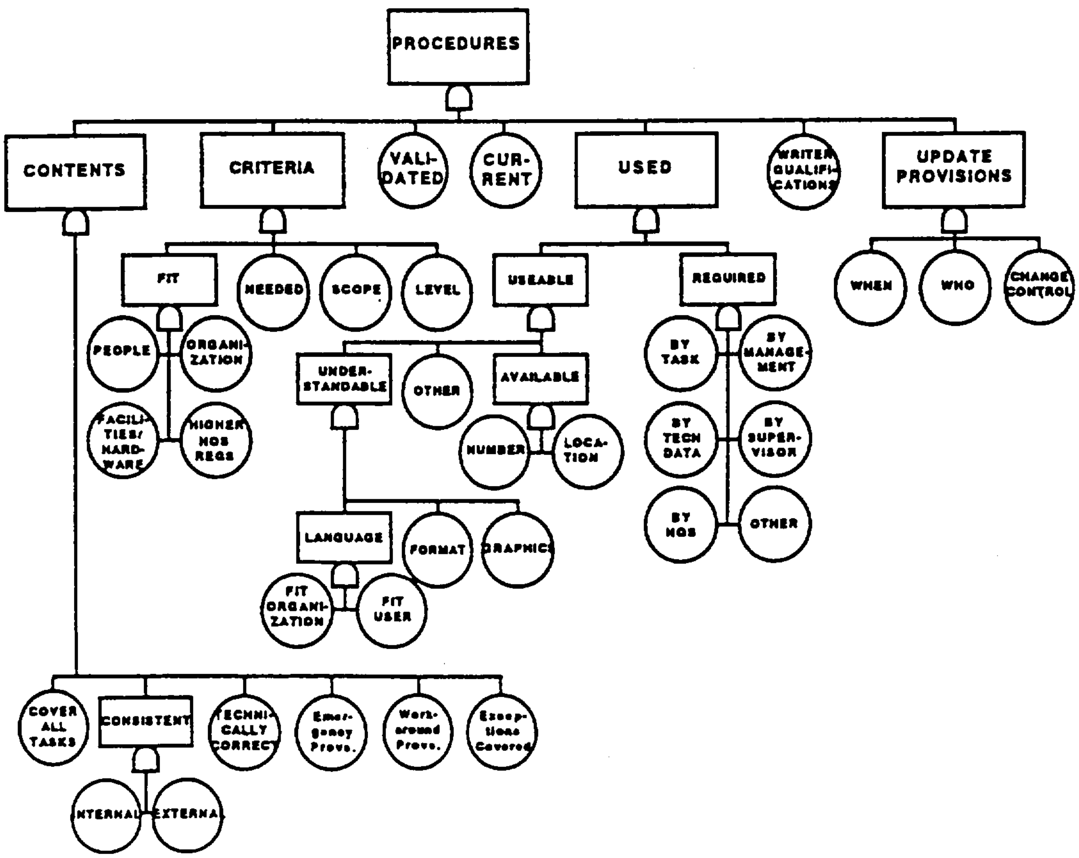


Figure 7-17. This branch of the PET chart deals with procedures.

With this technique, the natural course of accident events is plotted graphically against time. A second line is plotted that shows the positive effect of emergency responders on the natural course of events (i.e., decreasing the end-time of the accident). A second line also can be plotted that displays emergency response actions that made the natural course of events worse or prolonged the end-time of the accident (for example, by contributing to additional injuries). This technique begins with the accident, compares actual events and processes with an ideal response process, and continues until loss ceases.

Time loss analysis is not widely used in accident investigations; however, it can be useful in cases where additional response activities could have decreased the severity of the accident or where investigators suspect that emergency response actions were less than sufficient. Figure 7-18 displays a time loss analysis chart.

7.4.2 Human Factors Analysis

Human factors analysis identifies elements that influence task performance, focusing on operability, work environment, and management elements. Humans are often the weakest link in a system and can be the system component most likely to fail. Often machines are not optimally designed for operators, thereby increasing the risk of error. High-stress situations can cause personnel fatigue and increase the likelihood of error and failure. Therefore, methods that focus on human factors are useful when human error is determined to be a direct or contributing cause of an accident.

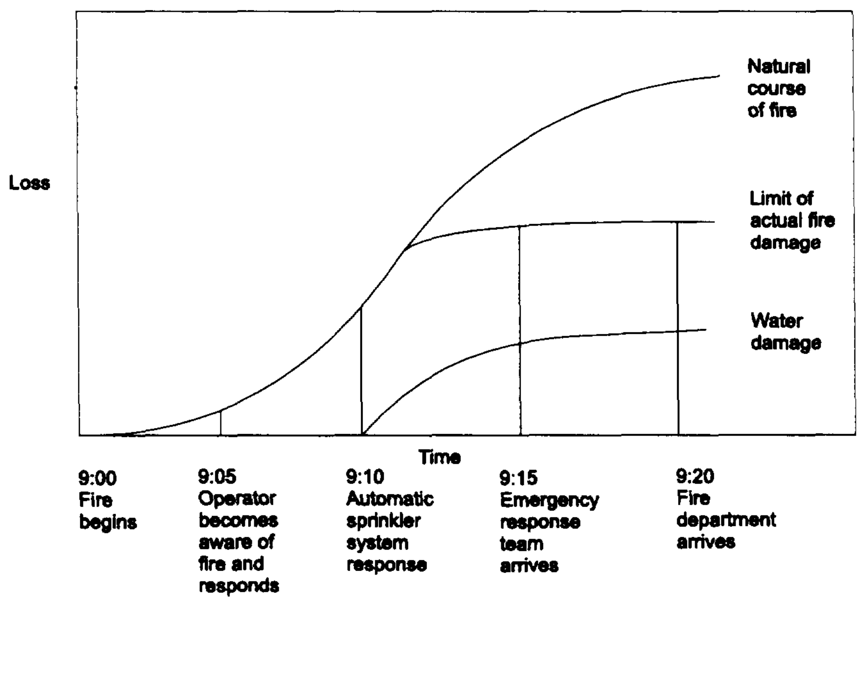


Figure 7-18. Time loss analysis can be used when emergency response is in question.

7.4.3 Integrated Accident Event Matrix

An integrated accident event matrix illustrates the time-based interaction between the victim and other key personnel prior to the accident and between the emergency responders and the victim after the accident. It analyzes at what time key personnel performed certain tasks both before and after the accident. This technique complements the events and causal factors chart, but is more specific about the timing of accident events; it is a simple and effective way to develop the accident scenario around the facts related to key personnel and appropriate tasks.

7.4.4 Failure Modes and Effects Analysis

This method is most often used in the hazard analysis of systems and subsystems; it is primarily concerned with evaluating single-point failures, probability of accidents or occurrences, and reliability of systems and subsystems. This technique examines a system's individual subsystems, assemblies, and components to determine the variety of ways each component could fail and the effect of a particular failure on other equipment components or subsystems. If possible, the analysis should include quantified reliability data.

7.4.5 Software Hazards Analysis

This analytic technique is used to locate software-based failures that could have contributed to an accident. This technique may be increasingly important in the future as more operations and systems associated with an accident become computerized and therefore dependent on software.

7.4.6 Common Cause Failure Analysis

Common cause failure analysis evaluates multiple failures that may be caused by a single event shared by multiple components. Common causes of failures in redundant systems are analyzed to determine whether the same failure contributed to the accident. The general approach to common cause failure analysis is to identify critical systems or components and then use barrier analysis to evaluate the vulnerability to common environmental hazards, unwanted energy flows, and barrier failures. This method is useful for accidents in which multiple barriers failed and a common cause failure contributed to the accident.

7.4.7 Sneak Circuit Analysis

A sneak circuit is an unanticipated energy path that can enable a failure, prevent a wanted function, or produce a mistiming of system functions. Sneak circuit analysis is mainly performed on electronic circuitry, but it can also be used in situations involving hydraulic, pneumatic, mechanical, and software systems. It identifies ways in which built-in design characteristics enable an undesired function to occur or prevent desired functions from occurring. Its importance lies in the distinction from component failure. Sneak circuit failure results from circuit design. Sneak circuit analysis generally employs inductive reasoning and is difficult to employ without the appropriate proprietary software.

7.4.8 Materials and Structural Analysis

Materials and structural analysis is used to test and analyze physical evidence. This technique has made significant contributions to developing credible scenarios and determining the cause of several accidents. It is used whenever hardware, material failure, or structural integrity is a possible issue, but the cause of the failure is unknown.

7.4.9 Design Criteria Analysis

This method involves the systematic review of standards, codes, design specifications, procedures, and policies relevant to the accident. This tool is useful in identifying whether codes exist, how standards or codes were circumvented, and codes or standards that should be in place to prevent recurrence. It can be used similarly to change analysis to examine the accident to determine whether work processes deviated from existing standards, codes, or procedures (i.e., was a piece of equipment used properly as designed and specified?)

7.4.10 Accident Reconstruction

Although not widely used in DOE accident investigations, accident reconstruction may be useful when accident scenes yield sketchy, inconclusive evidence. This method uses modeling to reconstruct the accident-related equipment or systems (i.e., from accident to pre-accident state). Good reconstruction can be more accurate than witness statements, because it applies the laws of physics and engineering.

7.4.11 Scientific Modeling

Scientific modeling models the behavior of a physical process or phenomenon. The methods, which range from simple hand calculations to complex and highly specialized computer models, cover a wide spectrum of physical processes (e.g., nuclear criticality, atmospheric dispersion, groundwater and surface water transport/dispersion, nuclear reactor physics, fire modeling, chemical reaction modeling, explosive modeling). For example, several computer models have been developed to predict the concentrations of hazardous materials in the air at downwind locations from a release. Such modeling is useful in characterizing the consequences of an accidental release of a hazardous material to the atmosphere. Similarly, nuclear criticality models (e.g., the SCALE package or the KENO code) can analyze scenarios that could lead to a critical configuration. In the event of a nuclear criticality, such models could be useful in understanding how the event occurred and what factors were important to the accident scenario (e.g., the presence of "moderating" or "reflecting" materials, such as water, can be very important).

Although useful in some circumstances, scientific modeling is not necessary for most accident investigations. It is only performed for accident scenarios involving complex physical processes (e.g., nuclear criticality, fires, "runaway" chemical reactions and explosions) and is not normally needed for typical occupational and industrial accidents. When scientific modeling is deemed appropriate, it should be performed at the direction of technically competent personnel (e.g., specialists, consultants, or board members who have the requisite technical backgrounds and familiarity with the models being used).

All scientific models have inherent assumptions and uncertainties that limit their accuracy. The board should recognize such limitations when considering the results of scientific models during the accident investigation process. Sometimes the facility in which an accident occurred may choose to perform scientific modeling and may provide those results to the board. In reviewing such results, the board should validate whether it is appropriate to obtain independent expertise to interpret the results and determine the validity of the modeling assumptions.

7.5 Determining Causal Factors

TIP

The process of determining causal factors seeks to answer the questions — what happened and why did it happen?

Causal factors are events and conditions that are necessary to produce or contribute to the unwanted event (accident). There are three types of causal factors:

- Direct cause
- Contributing causes
- Root causes.

7.5.1 Direct Cause

The direct cause of an accident is the immediate events or conditions that caused the accident. The direct cause should be stated in one sentence, as illustrated in the examples below.

Identifying the direct cause of an accident is optional. While it may not be necessary to identify the direct cause in order to complete the causal factors analysis, the direct cause should be identified when it facilitates understanding why the accident occurred or when it is useful in developing lessons learned from the accident.

EXAMPLES:
ACCIDENT DIRECT CAUSES

- The direct cause of the accident was contact between the chisel bit of the air-powered jackhammer and the 13.2-kV energized electrical cable in the sump pit being excavated.
- The direct cause of the fatal accident was the fall from an unprotected platform.

7.5.2 Contributing Causes

Contributing causes are events or conditions that collectively with other causes increase the likelihood of an accident but that individually did not cause the accident. Contributing causes may be based on longstanding conditions or a series of prior events that, while not important in and of themselves, collectively increased the probability that an accident would occur.

EXAMPLES:
ACCIDENT CONTRIBUTING CAUSES

- Failure to implement safety procedures in effect for the project contributed to the accident.
- Failure to erect barriers or post warning signs contributed to the accident.
- The standing work order process was used by facility personnel as a convenient method of performing work without a job ticket and work package, allowing most work to be field-directed.
- Inadequate illumination in the area of the platform created visibility problems that contributed to the fall from the platform.

7.5.3 Root Causes

Root causes are the causal factors that if corrected, would prevent recurrence of the accident. Root causes are derived from and generally encompass several contributing causes. They are higher-order, fundamental causal factors that address classes of deficiencies, rather than single problems or faults. They are identified using root cause analysis (see Section 7.2.5). In many cases, root causes relate directly to components of DOE's integrated safety management system. Root causes, as shown in the examples below, should focus on a single DOE or contractor line organization, management system, or safety system so that they can be easily understood.

Root causes can include system deficiencies, management failures, inadequate competencies, accepted risks, performance errors, omissions, non-adherence to procedures, and inadequate organizational communication.

TIP

Even though the board should avoid placing individual blame for an accident, the board has an obligation to seek out and report all causal factors, including deficiencies in management, safety or line management oversight systems.

EXAMPLES:
ACCIDENT ROOT CAUSES

- Contractor management failed to implement contractual requirements that defined responsibility and accountability for safety. These responsibilities were not exercised prior to the accident.
- Using the standing work order process, normally used for routine tasks, to accomplish nonroutine, complex modification and construction work was a root cause of the accident.
- Management systems were not effective in correcting longstanding, well defined programmatic weaknesses identified through internal and external assessments, past occurrences, and previous accident investigations or in translating lessons learned into safe day-to-day operations at the facility.
- Management failed to implement existing requirements that would have mitigated the hazards involved in the accident.

It cannot be overemphasized that the primary purpose of any accident investigation is to prevent recurrence through the identification and correction of root causes. Therefore, it is important for boards to avoid ending investigations before the root causes are identified. Instead, the board must continue to ask, "Why?" If a board cannot identify root causes, this should be stated clearly in the investigation report, along with an explanation.

KEY POINTS TO REMEMBER

Determining Facts

- Begin defining facts early in the collection of evidence.
- Develop an accident chronology (e.g., events and causal factors chart) while collecting evidence.
- Set aside preconceived notions and speculation.
- Allow the discovery of facts to guide the investigative process.
- Consider all information for relevance and possible causation.
- Continually review facts to verify accuracy and relevance.
- Retain all information gathered, even that which is removed from the accident chronology.
- Establish a clear description of the accident.

Conducting the Analysis

Four core analytic techniques are generally used in DOE accident investigations:

- **Events and causal factors charting and analysis:** used to trace the sequence of events surrounding an accident, as well as the conditions present for the accident to occur
- **Barrier analysis:** used to examine the effectiveness of three types of barriers (administrative, supervisory/management, and physical) intended to protect persons, property, and the environment from unwanted energy transfers
- **Change analysis:** used to examine planned or unplanned changes in a system and determine their significance as causal factors in an accident
- **Root cause analysis:** used to identify the causal factors, including management systems, that, if corrected, would prevent recurrence of the accident.

Each of these technique has strengths and limitations that should be reviewed before applying it to any given accident. However, the use of the core analytical techniques should be sufficient for most accident investigations. Other techniques are available for complex accidents or when there are special circumstances or considerations. Some of these techniques are MORT, PET, materials and structural analysis, design criteria analysis, integrated accident event matrix, and scientific modeling. Other techniques are available for complex accidents or special accident circumstances.

Analytical techniques are used to determine the causes of an accident. There are three types of causal factors: the **direct cause**, **contributing causes**, and **root causes**.

KEY POINTS TO REMEMBER (Continued)

The following should be considered when performing analyses:

- Chart events in chronological order, developing an events and causal factors chart as initial facts become available.
- Stress aspects of the accident that may be causal factors.
- Establish accurate, complete, and substantive information that can be used to support the analysis and determine the causal factors of the accident.
- Stress aspects of the accident that may be the foundation for judgments of need and future preventive measures.
- Resolve matters of speculation and disputed facts through board discussions.
- Document methodologies used in analysis; use several techniques to explore various components of an accident.
- Qualify facts and subsequent analysis that cannot be determined with relative certainty.
- Conduct preliminary analyses; use results to guide additional collection of evidence.
- Analyze relationships of event causes.
- Clearly identify all causal factors.
- Examine management systems as potential causal factors.
- Consider the use of analytic software to assist in evidence analysis.

Barrier Analysis Worksheet

Hazard	Direct Barrier or Control Failure	Possible Contributing Factors to Barrier or Control Failures	Possible Root Causes of Failures	Loss or Potential Loss Event	Evaluation

Change Analysis Worksheet

Factors	Accident Situation	Prior, Ideal, or Accident-Free Situation	Difference	Evaluation of Effect
WHAT Conditions, occurrences, activities, equipment				
WHEN Occurred, identified, facility status, schedule				
WHERE Physical location, environmental conditions				
WHO Staff involved, training, qualification, supervision				
MANAGERIAL CONTROLS Control chain, hazard analysis monitoring				
Other				

NOTE: The factors in this worksheet are only guidelines but are useful in directing lines of inquiry and analysis.

PET Analysis Worksheet

Prepared by: ______________________
Date: ______________________
Accident Investigation: ______________________

Item No.	Item Evaluated	PET Event	Color	Problem/Comments	Responsible Person/Agency	Status	Final Completion Date